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Evaluation of Equity in the Cadaver Kidney Allocation System- A Case Study from India

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ABSTRACT: Cadaver kidney transplantation requires the selection of a recipient from a large pool of patients waiting across various geographic zones, making the process challenging and complex. For improving efficiency of transplantation, the selection has to be made from a pool of recipients waiting in the same allocation zone as that of the identified donor. Equity issues often arise due to geographic disparity in the allocation system. Many deserving patients fail to get a kidney on time because they are in the wrong geographic zone. This work evaluates the geographic disparity issues in one of the states of India, Kerala. The geographic disparity in the allocation is illustrated using a demand-supply gap analysis performed across various kidney allocation zones of the state. The future demand-supply gap across the various allocation zones is projected is using time series models. The results revealed the presence of huge demand-supply gap along with geographic disparity in the current system with the south zone of the state facing maximum demand-supply gap compared to the other two zones. The demand-supply gap of cadaver kidneys is growing at extremely different rates in different allocation zones. Therefore, there is a need to develop an allocation algorithm which can strike an optimum balance between equity and efficiency.

KEYWORDS: Kidney Transplantation, Time series models, Demand supply gap, Equity.

I. INTRODUCTION

An end stage renal disease, popularly known as ESRD is one of the worst case of kidney disease, where a patient needs either dialysis or transplantation for survival. Although living donor transplantation is known to offer benefits like shorter transplant waiting time and higher survival rates, the cadaver transplant program in many countries has witnessed huge waiting list numbers in the past. At present, India is having state specific transplant programs like Tamil Nadu Network for Organ Sharing, Kerala Network for Organ Sharing (KNOS) etc. The cadaver transplant program of Kerala was established on August 2012. As per the Kerala Network for Organ Sharing (KNOS) statistics, around 1185 patients are waiting as on 4th January 2016 [1].

Equity deals with the fairness of allocation with respect to various sub-groups. For instance, many researchers argue that the allocation policy shall not favour patients from a specific race or region. On the other hand, efficiency of allocation demands a longer use of allocated organs. Transplant waiting time and issues of geographic disparity in access to transplantation are widely researched topics in the field of cadaver kidney transplantation. A longer waiting time on dialysis was found as a significant risk factor for death-censored graft survival and patient death with functioning graft after renal transplantation [2]. Some other researchers primarily measured demand by ESRD incidence and examines its effect on access to transplantation. It is to be noted from this work that the ESRD incidence varies with population risk factors and is growing with different rates in different parts of the country [3]. Kadry examined geographic disparity aspects in US Liver allocation system with special reference to hepatocellular cancer patients [4]. Stanford examined the equity of waiting times with respect to blood groups [5].



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For an efficient organ allocation, the state of Kerala is divided into three zones namely north, south and central. These zones comprises of various districts in Kerala clustered based on their geographical proximity to each other. There is no doubt that the zone based allocation helps to improve efficiency by reducing the cold ischemic time; but it is pertinent to evaluate the equity in the present system. Equity in the context of healthcare can be considered as equality of access to treatment or healthcare facilities.

A possible way of evaluating the equity of the present allocation system would be to conduct a demand-supply gap analysis across the three geographic zones of Kerala. Providing equal transplantation access to all deserving patients irrespective of their location should be one of the prime objectives of any organ allocation program. This work explores the demand-supply gap by utilizing the times series models. The focus of the work relies primarily on bringing out the big-picture of demand-supply gap to various stakeholders associated with transplantation since the estimates of the future gap is crucial to envisage the formulation and implementation of strategies which could possibly mitigate or even eliminate the repercussions of such a situation. Also, the results of the demand-supply gap across the geographic zones of Kerala, can act as an impetus for scientifically designing the geographic zones based on a whole set of criteria including demand, supply, health infrastructure, logistics etc.

II. METHODS

The previous section pointed out the significance of geographic location in getting access to cadaver kidney transplantation. Quantifying the present demand-supply gap and projecting the future gap can help to evaluate how worse the geographic disparity in kidney allocation can grow in future. The entire analysis is based on KNOS registry data. Input variables are selected based on the discussion with KNOS faculty members. The succeeding portion describes the basic assumptions and techniques used in the gap analysis.

Demand supply gap analysis: A demand supply gap is the difference between demand and supply of cadaver kidneys. The demand of cadaver kidneys at any time period is the difference between the number of active waiting list registrations up to that period and the number of transplants performed until the previous period. The gap between demand and supply at the end of any time period t is given by the following equation.

Gap_t=Demand_t-Transplants_t

The gap analysis is performed for three allocation zones of Kerala namely north, south and central. The gap analysis is carried out under the following assumptions.

- 1. The supply of kidneys is taken equivalent to the number of transplants. However the success or failure of the performed transplant does not come under the scope of the analysis.
- 2. The numbers of transplants were calculated based on 80% utilization of available donors. A donor can yield 0, 1 or 2 kidneys based on the medical suitability of the organs. For instance, if a particular quarter witnessed 10 donors, there could be 16 transplants happening based on 80% utilization. Utilization is the ratio between total number of kidneys procured successfully and the maximum possible number of kidneys available. The value of utilization is selected based on the past statistics from KNOS.
- 3. The number of transplants happening in any particular quarter is dependent on the number of brain death patients, which is highly random and exact prediction of the number of transplants is impossible. Therefore actual transplants are assumed to be a random number in the range of transplants calculated using assumption II. The present study allocates random transplants based on two variation measures a) range of probable transplants b) interquartile range of probable transplants. The first case allows maximum fluctuations in the number of transplants, while the second case assumes a comparatively stable picture of transplants.
- 4. It is assumed that the number of transplants are always less than or equal to the requirement.
- 5. Both supply and demand is assumed to be continuous for time series modelling.



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6. No restrictions are imposed on the style of growth of demand-supply gap. For instance, the gap could follow a seasonal pattern or a linear trend.

The future gap is estimated using time series forecasting techniques. The various exponential smoothing time series models (Gardner, 1985) considered for forecasting the future demand-supply gap is shown in Table 1 [6]. Apart from these exponential smoothing models, the analysis also considered ARIMA models.

No.	Time series model	Applicability of the model
1	Simple	Data which does not exhibit trend or seasonality
2	Holt's linear trend	Data which exhibits a linear trend
3	Brown's linear trend	Data which exhibits a linear trend, which is equal to the level
4	Damped trend	Data which exhibits a linear trend that is dying out.
5	Simple seasonal	Data which exhibits no trend and a seasonal effect that is constant over time
6	Winters additive.	Data which exhibits a linear trend and a seasonal effect that does not depend on the level of the series.
7	Winters multiplicative.	Data which exhibits a linear trend and a seasonal effect that depends on the level of the series.

The existing gap is calculated for the three zones and the best fit time series models are used to forecast the future gap. R squared is used as the best fit evaluation criteria. The forecast for the future gap will help to anticipate the geographic disparity and hence plan effective methodologies and procure enough resources to manage the same. The succeeding sub-section presents the details of inputs used for the gap analysis.

Gap analysis inputs: The study covered 1087 patients and 139 donors who registered between January 2013 and September 2015. The model inputs consists of waiting list registrations per quarter and transplants per quarter. The data on patient registrations and kidney donations were obtained from KNOS. The demand-supply gap is found using equation 2.1. The value of gap between demand and supply at any quarter for any zone is used the data input to the gap forecasting model. Since the cadaver transplant program of Kerala is in its budding stage and due to the scarce supply of kidneys, the chances of a transplant happening during a particular time period cannot be predicted accurately. In order to account for this highly fluctuating case of transplants, the number of probable transplants is computed using random numbers by assuming two different transplant rate variance scenarios. The number of transplants per quarter is computed based on the available data of number of donors per quarter. Based on the available number of donors for various quarters of the study period, the probable number of transplants is calculated based on 80% utilization. The descriptive statistics for the probable number of transplants is shown in Table II. Table II shows a median transplant per quarter (50th percentile) of 4, 4 and 12 across the north, south and central zones respectively. It is seen that, central zone is having the potential for carrying out transplants as high as 21 per quarter, while north zone is capable of having a maximum transplant rate of 8 per quarter. The range of probable transplants is the difference between maximum and minimum values, while the interquartile range is the difference between 75^{th} and 25^{th} percentile values. The actual number of transplants is found by using random numbers allocated in the range



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Table II. Descriptive statistics for the probable number of transplants per quarter						
		North	South	Central		
Mean		3.91	5.09	12.36		
Minimum	Ainimum		2	2		
Maximum		8	12	21		
Percentiles	25	2.00	4.00	8.00		
	50	4.00	4.00	12.00		
	75	7.00	5.00	15.00		

as well as interquartile range of the probable number of transplants. These values are taken equivalent to supply and gap calculations are performed as per the previously mentioned equation. These two scenarios are selected to analyse the effect of fluctuating supply on the future gap. The calculated data on present gap across the three regions is given as input to the expert modeller in IBM SPSS software. The analysis has given best fitting gap models for each of the scenarios. The detailed results are presented in the next section.

III. RESULTS AND DISCUSSION

The summary of best fitting gap models obtained for various scenarios are shown in Table III. Models 1, 2 and 3 represent the forecast under the situation in which the transplants occur randomly within the range of probable transplants in the north, south and central zones respectively. The models 4, 5 and 6 represent the forecast under the situation in which the transplants occur randomly within the interquartile range of the probable transplants in the north, south and central zones respectively. The summary of forecasting results is represented in Table IV.

Table IV shows the forecasted values of the gap for various quarters starting from quarter four, 2015 to quarter 4, 2017. The forecast values as well as the upper confidence limit of the forecast values are shown in the table. For instance, model 1 shows demand-supply gap forecast of 279.61, and 312.22 for quarter four-2015 and quarter one-2016 respectively. The upper confidence limit values shows a forecast of 312.02 and 376.12 for the previously mentioned quarters, which means that the gap could go as high as 312.02 and 376.12 by the end of their respective time periods. From Table IV, it is seen that all the forecasting models exhibited good fit since the R-squared values for all the cases are greater than 0.9. The R- squared value explains the capability of the model to explain the variations in the data. An R squared of 0.976 for the first model in Table IV means that the forecasting model (in this case, Holts model) can explain 97.6% of the variations in the data. As per the model results, there will be around 541 patients waiting in the north zone by the end of the year 2017. This number is around twice the number of patients waiting by the end of the year 2015. The calculations for this model are based on the assumption that the transplants are random numbers falling in the range of probable number of transplants. This result implies the possibility of more and more patients joining the demand pool of the north zone with the same level of supply. The increased number of patients in the demand pool could be due to the shift of patients from living donor program to cadaver transplant program. More dismaying aspect is the case of supply since it is well known that sudden increase the supply of kidneys is an impossible case. It is well known that latest practices like the dual transplant program is adversely affected by a cadaver transplant program, which is still in its infancy [7]. Also, the cadaver kidney supply is dependent on a large number of medical as well as non-medical factors. For example, the presence of knowledgeable and eligible doctors who can identify and certify brain death is a major determinant of kidneys utilized in a particular hospital and zone. Medical facilities and basic infrastructure present in a zone can influence its gap. For instance, a poorly developed kidney sharing transportation network could potentially increase the cold ischemic time and makes the kidneys unfit for use. A gap in all these aspects could ultimately lead to geographic disparity between various zones.



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Table III. Best fitting gap models								
Model Id	Zone	Nature of variation in the probable number of transplants	Best fit model representing the growth of demand-supply gap					
Model 1	North	Within range	Holt					
Model 2	South	Within range	ARIMA(0,1,0)					
Model 3	Central	Within range	Holt					
Model 4	North	Within interquartile range	Winters' Additive					
Model 5	South	Within interquartile range	Holt					
Model 6	Central	Within interquartile range	ARIMA(0,2,0)					

The forecasting results show that the gap is increasing for all the scenarios, with a linear trend in all the forecasting models. The predictions are made for two scenarios. The first scenario accounts for higher variability of transplants, assuming that the transplants happen within the range of probable transplants. The second scenario is based on more stable and less variable number of transplants. Assuming a higher variability in transplants, the model results predict that there will be around 1699 non-allocated patients by the end of the year 2017. The results based on interquartile range of transplants show that there will be around 2284 non- allocated patients by the end of the year 2017. Both the results show an alarming increase in the waiting list numbers. Failure to give adequate allocation priority for the medical condition of the patient could probably lead to a number of patient deaths while waiting for a kidney. The results could also manifest in the form of huge demand for live-unrelated donors which could lead to exploitation of poor donors or illegal organ trading [8].

Looking at the zone based results; south zone appears to have serious problems associated with high demand and low supply. Both the scenarios, unanimously predict that south zone will be the most adversely affected zone in near future. As per the forecasting model, first scenario with higher variance of transplants predicts an almost similar gap for the north and central zones and the second scenario predicts a higher gap for the central zone. The forecasting models predicted an almost equal or higher gap for the central zone compared to north zone because of the fact that the arrivals in central zone exhibited higher variance of arrivals along with few outliers.

The results show the influence of randomness of availability of donors on the demand-supply gap. A model allowing extreme variations in the number of transplants per quarter can definitely bring down the gap in a zone as in the case of models based on inter quartile range. But such a model can be detrimental to the allocation equity between zones. The present system should be transformed into a stage where there are stable and comparable numbers of transplants happening in the allocation regions. This is possible by either empowering the weak zones with a strong supply harnessing network or by reducing demand for transplantation in these zones. Also, there should be a scientific redistricting of the allocation regions in order to balance equity and efficiency. Irrespective of the problem of geographic disparity in the allocation system, the results show an acute shortage of cadaver kidneys in all the allocation zones. Extremely low awareness on the concept of brain death is reported to be one of the primary reasons for poor kidney supply [9]. Also, there is evidence suggesting a growing link between poverty and CKD [10]. Due to financial problems, many ESRD patients resort to government hospitals for their treatment. The problems of geographic disparity and low cadaver kidney supply adversely affects the poor and underprivileged and can even go up to the extent of depriving their fundamental right to life. Thus the results highlight the need for strengthening the public health infrastructure of the adversely affected geographic zones. There should be a continuous drive for cadaver organ donation lead by the politicians, film stars and cricketers [11]. Also, there is a need for allocation algorithm which can incorporate the aspects of equity in the allocation process.



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Table IV. Summary of forecasting results for demand-supply gap

6		Q4 2015	Q1 2016	Q2 2016	Q3 2016	Q4 2016	Q1 2017	Q2 2017	Q3 2017	Q4 2017	R squared
Model Id											
Model 1	Forecast	279.61	312.22	344.82	377.43	410.04	442.65	475.25	507.86	540.47	0.976
	UCL*	312.02	376.12	445.47	519.61	598.11	680.60	766.79	856.46	949 <mark>.4</mark> 1	
Model 2	Forecast	367.70	398.40	429.10	459.80	<u>490.50</u>	521.20	551.90	582.60	613.30	0.938
	UCL	416.03	466.75	512.81	556.46	598.57	639.59	679.77	719.30	758.29	
Model 3	Forecast	275.72	309.45	343.17	376.89	410.62	444.34	478.07	511.79	545.51	0.972
	UCL	309.41	378.80	454.86	536.84	624.12	716.23	812.82	913. <mark>5</mark> 9	1018.29	
Model 4	Forecast	264.88	312.96	348.51	373.59	410.47	458.55	494.11	519.19	556.06	0.978
	UCL	296.15	367.84	433.48	493.53	573.47	663.48	744.55	818.41	910.23	
Model 5	Forecast	435.86	503.97	572.08	640.20	708.31	776.42	844.53	912.65	980.76	0.974
	UCL	475.90	579.53	694.35	817.32	947.14	1083.01	1224.40	1370.91	1522.20	
Model 6	Forecast	295.89	338.67	385.33	435.89	490.33	548.67	610.89	677.00	747.00	0.977
	UCL	328.33	411.20	506.70	613.56	730.89	858.10	994.69	1140.29	1294.6	

IV. CONCLUSION

In developing countries like India, CKD has adversely affected the society by marking a much early incidence. This creates a huge ESRD burden in countries like India, Pakistan and Bangladesh. At the same time, access to renal replacement therapy is limited to less than a quarter of the patients projected to develop ESRD in the developing regions of the world [12]. If properly implemented, the cadaver kidney transplantation program can reduce the intensity of the huge ESRD burden.

The study analysed the growth of cadaver kidney demand-supply gap across various zones in Kerala using time series forecasting models. The results presented an alarming picture of huge demand-supply gap, characterised by an increasing linear trend. The increasing waiting list numbers with scant supplies make the kidney allocation problem challenging and complex. The results showed that south zone of Kerala is the zone with maximum demand-supply gap. This is pointing towards geographic disparity in the system. The results highlight the need for increasing organ



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donation awareness campaigns and strengthening the public health infrastructure of adversely affected geographic zones. Also, efforts should be made to develop an allocation algorithm which can strike a balance between efficiency and equity. The gap analysis models could be improved by adding more predictors, which could explain the reason for such a growth.

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